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A LATE HOLOCENE RECORD OF VEGETATION AND CLIMATE FROM A SMALL WETLAND IN SHASTA COUNTY, CALIFORNIA

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ABSTRACT

A long-term history of water table fluctuations, from alternating periods of drought and abundant precipitation, can be preserved in the stratigraphy of wetland sediments. We examined the middle to late Holocene history of vegetation and climate change from a small wetland on the Modoc Plateau in Shasta County, northeastern California. This site is at a transition between the Great Basin and the Californian Floristic Provinces, and the paleoecological record from Flycatcher Basin exhibits affinities to both. Although the sedimentary record extends back to ca. 8300 cal yr BP, organic sediment did not form until ca. 4500 cal yr BP, indicating that water was probably absent in the basin during the middle Holocene. Pollen and plant macrofossils deposited after 4500 cal yr BP suggests a mixed conifer – *Quercus* forest grew around Flycatcher Basin. Charcoal is abundant in these sediments, indicating periodic forest fire. Distinctly modern forests developed by about 2200 cal yr BP, when *Pinus* became the dominant conifer with *Quercus*, in a more closed forest, perhaps with more frequent fire. The record from Flycatcher Basin provides no evidence for change in the boundaries between the Great Basin and California (Cascadian) floristic provinces during the period of record. The late Holocene is interpreted as a generally increasingly mesic sequence, with a long-term increase in groundwater recharge, yet interspersed by extended drought during the last 2000 yr. Extended droughts occurred from ca. 1125 AD to 1450 AD, with an earlier protracted dry period from ca. 100 AD to ca. 900 AD. Generally wetter periods occur from ca. 1000 to 1125 AD, and after ca. 1450 AD. The paleoenvironmental changes in the Flycatcher Basin wetland are a local expression of a much broader climatic pattern, as shown by several studies of higher resolution proxies. The record from Flycatcher Basin wetland is important in demonstrating the centennial to millennial-scale fluctuations in water availability in a region of rapidly expanding human population, with an increasing need for water resources.

Key Words: California, drought reconstruction, fire history, paleoecology, pollen analysis, wetland hydrology, Modoc Plateau.

The Modoc Plateau of northeastern California is a region of steep vegetation gradients from interior basin to upland forest. Located at the transition between the Great Basin, the southern extension of the Cascade Range and the northern extent of the Sierra Nevada, the Plateau is presently home to vegetation types allied to Sierran – Cascade coniferous forests, as well as to Great Basin sagebrush steppe (Küchler 1988). To the west, on the flanks of the Cascade Range, are the Sierran montane forests, which include ponderosa and Jeffrey pine (*Pinus ponderosa* Laws., *P. jeffreyi* Grev. & Balf.), white fir (*Abies concolor* (Gordon & Glend.) Lindley)), California black oak (*Quercus kelloggii* Newb.), and western juniper (*Juniperus occidentalis* Hook.), among others (Rundel et al. 1988). At somewhat lower elevations, Oregon oak (*Q. garryana* Hook.) woodland dominates. South-facing xeric slopes support gray pine (*P. sabiniana* Douglas) and chaparral, including buckbrush (*Ceanothus prostratus* Benth.) and manzanita (*Arctostaphylos* spp.). To the east is Great Basin vegetation, dominated by sagebrush (*Artemisia tridentata* Nutt.) and *Juniperus occidentalis*, with additional shrubby perennials.

Occurring within this transitional region, less than 10 km east of the Great Basin, is a series of small ephemeral wetlands, known informally as the Flycatcher Basins (Fig. 1). The small wetlands lie within a canyon created by the Pit River's course through the southern Cascade Range. The Flycatcher Basin wetlands occupy hollows in jumbled terrain of probable landslide origin (Page 1995), are unusual in this relatively dry environment, and preserve a paleoenvironmental record of mid- through late Holocene. This is important since our knowledge of former environments of this region is limited to just a few sites. Prior to 1990, only three studies had been conducted on or near the Modoc Plateau, including Klamath Lake (Hansen 1942), Tulelake

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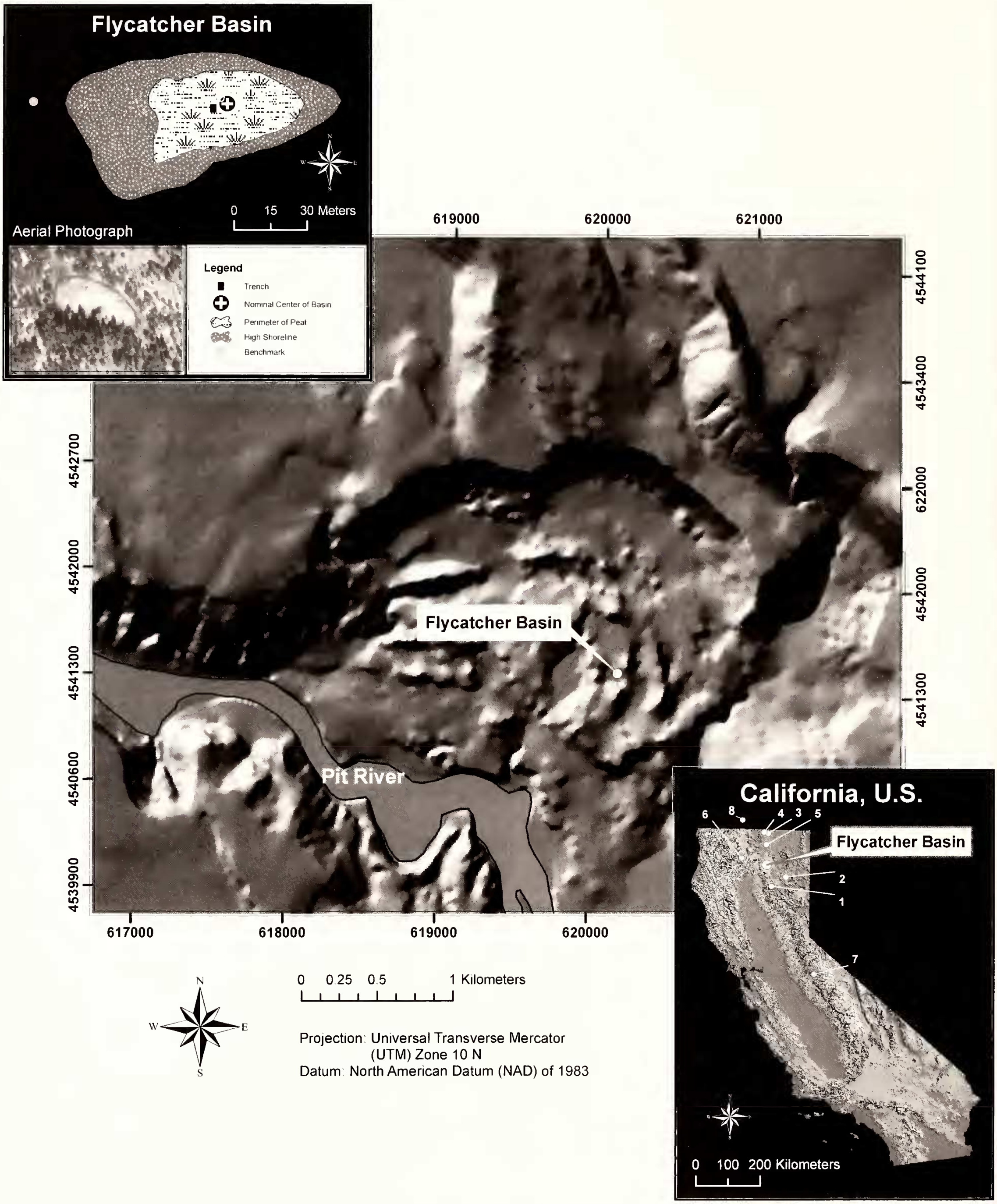

FIG. 1. Location of Flycatcher Basin, Shasta County, northeastern California. The center image clearly shows the slump terrain along the Pit River that produced the basins. The small inset in the upper left shows the basin itself and coring site. The inset in the lower right shows sites mentioned the text (1 = Little Willow Lake [West 2004]; 2 = McCoy Flat [Wigand and Rhode 2002]; 3 = Tulelake [Adam et al. 1989]; 4 = Lower Klamath Lake [Hansen 1942]; 5 = Medicine Lake [Starratt et al. 2003]; 6 = Klamath Mountains lakes [Mohr et al. 2000; Daniels et al. 2005]; 7 = Sierra Nevada sites [Anderson 1990; Smith and Anderson 1992; Anderson and Smith 1994; Edlund 1996; Brunelle and Anderson 2003; Potito et al. 2006]; 8 = Southern Oregon lakes [Bradbury et al. 2004; Hakala and Adam 2004]).

(Adam et al. 1989), and Diamond Craters (Mehringer and Wigand 1990). More recently, additional long records of vegetation change have come from Upper Klamath and Grass Lakes in southern Oregon (Bradbury et al. 2004; Hakala and Adam 2004), Medicine Lake (ca. 50 km north of Mt. Shasta; Starratt et al. 2003), Little Willow Lake (Lassen National Park; West 2004), and McCoy Flat (eastern fringe of Modoc Plateau; Wigand and Rhode 2002). To the west, Mohr et al. (2000) and Daniels et al. (2005) determined postglacial vegetation and fire history from the Klamath Mountains, while several studies come from the Sierra Nevada to the south (e.g., Anderson 1990; Smith and Anderson 1992; Anderson and Smith 1994; Edlund 1996; Brunelle and Anderson 2003; Potito et al. 2006). Though the Klamath Lake record appears to be largely Holocene, radiocarbon dates are absent and its exact chronology is unknown. The Tulelake record encompasses much of the last three million years, but few Holocene samples were analyzed. Thus additional records from the region are needed to understand past vegetation changes that have occurred here.

Recent studies of the late Holocene of the region using multiple proxies point to periodic, but widespread and persistent dry conditions over the last 2000 yr that are greater in magnitude than those experienced during the historic period (e.g., the 1930's and 1950's droughts [Schubert et al. 2004]). These include lower lake levels (Stine 1994) and reduced runoff (Benson et al. 2002), higher fire frequencies (Mohr et al. 2000; Brunelle and Anderson 2003; Daniels et al. 2005), reduced tree growth (Hughes and Graumlich 1996), and lowered treelines (Lloyd and Graumlich 1997) in and near the California mountains. These droughts are a regional expression of widespread periodic drought in western North America (e.g., Grissino-Mayer 1996; Laird et al. 1996; deMenocal 2001; Fye et al. 2003; Mason et al. 2004) during the late Holocene.

The Site

Flycatcher Basin is one of several small closed basins supporting wetlands, located within a large landslide known as the Flycatcher Embayment, ca. 1.2 km northeast of the Pit River, in Shasta County, California (Fig. 1). Bedrock along the Pit River here is Pliocene diatomite overlain by basalt. The diatomite is a structurally weak rock prone to landslides (Page 1995). The basin is located at ca. 924 m elevation and has a small drainage area within the local forest with no tributary streams or channels. Although dry during the period of excavation, a cracked peat-mud floor, pond turtle (*Chlemys marmorata*) bones, and a wave-cut shoreline indicated that it recently held water to a depth of at least 1.1 m.

Uplands surrounding the basin are typically closed-canopy Oregon oak (*Q. garryana*) woodland with *Pinus ponderosa*. Dense *P. ponderosa* forest occurs on the north-facing slope immediately south of the basin. *P. sabiniana* and *Ceanothus prostratus* occur within an open *Quercus* woodland on the adjacent south-facing slope. Other trees and shrubs occurring locally include rare Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco), scattered *Juniperus occidentalis*, wild rose (*Rosa* sp.), waxberry (*Symphoricarpos* sp.), squawberry (*Rhus trilobata* Torry & A. Gray), buck brush (*Ceanothus cuneatus* (Hook.) Nutt.), and antelope bush (*Purshia tridentata* (Pursh) DC). A variety of herbs and subshrubs, including grasses (Poaceae), composites (*Achillea millefolium* L., *Artemisia* cf. *dracunculus* L., *Cirsium* sp., *Xanthium strumarium* L.), *Epilobium brachycarpum* C. Presl and others occur within the basin. Woody phreatophytes such as willow (*Salix* sp.) and alder (*Alnus viridis* (Chaix) DC ssp. *sinuata* (Regel) A. Löve & D. Löve) do not occur along the margins of the basin, but are found along the Pit River to the south. Plants growing within the basin itself include sedges (Cyperaceae), dock (*Rumex* sp.), mullein (*Verbascum thapsus* L.), and plantain (*Plantago* sp.), with patches of tule (*Scirpus* sp.) and rushes (*Juncus* sp.) in wetter areas.

Methods

Sediments from Flycatcher Basin were collected during September 1992. A 1.5 × 2 m trench was hand excavated to a depth of 2.1 m near the middle of the desiccated basin (Fig. 1). The top 40.5 cm of sediment was retrieved in consecutive blocks of 4 to 22 cm length. Below this a 10-cm diameter pipe with a sharpened end was driven vertically into the exposed section to 170.5 cm depth. From 170.5 to 208.5 cm blocks of sediment were cut from the exposure in the same manner as the top 40.5 cm. The multiple methods were used to obtain as much of the sedimentary column intact as possible. Until analyzed in 1994, these sediments were kept in cold storage at the Laboratory of Paleoecology (LOP), Northern Arizona University.

For pollen and charcoal analysis, 42 subsamples (2 cm^3 each) were taken at intervals of 2 to 15 cm. Three additional surface pollen samples were obtained from deposits elsewhere in the basin. Pollen and charcoal were extracted using a Fægri and Iversen (1989) chemical separation technique, additionally treated with sodium pyrophosphate and sieved through an 8-μm screen following acetolysis. Pollen preservation was variable, so the number of pollen grains identified per sample was not uniform (see below). We analyzed the microscopic charcoal fraction here, since macroscopic charcoal occurred less commonly in the record.

TABLE 1. RADIOCARBON AND CALENDAR AGES FOR THE FLYCATCHER BASIN SEDIMENTS. * median probability age

Laboratory number	Depth (cm)	Age (^{14}C yr BP)	Age (cal yr BP)*	Age (AD/BC)*
Beta-64384	15–20	430±60	473	1477 AD
Beta-62111	40.4–50.5	1240±70	1159	791 AD
Beta-68120	65–70	2080±80	2054	105 BC
Beta-62112	125–135	3580±80	3876	1927 BC
Beta-62310	192–208.5	7420±170	8217	6268 BC

Pollen types were identified by comparison to the reference collection at the LOP. Most grains were identified to genus (e.g., *Pinus*), less often to species or species-type. Some pollen types can only be distinguished reliably to family (e.g., Asteraceae, Apiaceae, Poaceae). Though most of the Cupressaceae pollen was undoubtedly *Juniperus*, we retain the designation of the family. All of the *Polygonum* pollen belonged to an aquatic species (i.e., *P. amphibium* L.). We used the TGView 2.0 program (Grimm 1993) to calculate sums and graph data (the pollen data are available from the North American Pollen Database (NAPD [http://www.ngdc.noaa.gov/paleo/napd.html]), but pollen zones were created by visual inspection. In order to highlight potential hydrological changes in the basin we calculated a ratio of pollen percentage of "moist" taxa to a sum of "moist" and "dry" pollen types, such as:

$$(\textit{Polygonum amphibium} + \textit{Alnus} + \textit{Potamogeton} + \text{Cyperaceae}) / (\textit{Polygonum amphibium} + \textit{Alnus} + \textit{Potamogeton} + \text{Cyperaceae}) + (\text{Asteraceae} + \text{Cheno} - \text{am}).$$

Charcoal fragments were identified on pollen slides, and the area of each individual charcoal particle was measured, then the total area (mm^2) of charcoal was calculated for each sediment level analyzed.

Plant macrofossils were recovered by extracting subsamples (ca. 300 cm^3 each) from the sediments at ca. 10-cm intervals. The volume of each subsample was estimated by the amount of water displaced in a beaker. Sediments were disaggregated in water, and sieved by gentle water washing. Each fraction was hand-sorted and picked for plant and animal macrofossils. Macrofossils were compared with the LOP reference collection.

RESULTS

Radiocarbon Dates and Sediment Accumulation Rates

Five bulk sediment radiocarbon dates were obtained (Table 1), and radiocarbon ages were converted to calendar ages (cal yr BP and AD/BC) using CALIB 5.0.2 (Stuiver et al. 1998). For age-depth construction, we chose the median probability age (Telford et al. 2004) from the output of CALIB 5.0.2, with a linear interpolation between ages. Sediment accumulation rate (SAR) was slowest (0.02 cm/yr) from the profile bottom to ca. 130 cm depth (Fig. 2). Above 130 cm, SAR varied from 0.03 to 0.04 cm/yr. These SAR's are comparable to those obtained from other lakes in California (Anderson 1990), despite the fact that this is a small basin with no tributaries.

Sediment Stratigraphy

The section top from 0 to 10 cm is composed of dry, largely unconsolidated, dark gray-brown silty peat (Fig. 2). From 10–110 cm sediments are compact, prismatic, dark brown clay with interspersed flecks of charcoal. These sediments contain very little organic material or sand. At ca. 110 cm depth, this fine-grained sediment grades gradually into a reddish-brown, silty-sandy clay with occasional gravel inclusions. Increasing amounts of sand were found below 122 cm. Below 175 cm sediments are sandy, brown, friable clays.

Modern Pollen Assemblages

Three pollen samples provide modern pollen assemblages for comparison with the fossil pollen. Samples were taken from a patch of *Scirpus*, near a former shoreline of the pond, and from the top of a trench dug in the southern portion of the basin (Fig. 3). Each sample was dominated by *Pinus*, varying from ca. 55–75% of the pollen sum. Other important pollen types include Cupressaceae (probably *Juniperus*), *Quercus*, and *Abies*. Cupressaceae appears over-represented based on its near-absence from the local vegetation, and *Quercus* appears under-represented compared to its dominance in the local woodland. Very small amounts (ca. 5%) of *Artemisia* were also recovered. The occurrence of both *Abies* and *Artemisia* in sediments suggests pollen sources from both the west (the dominant wind direction resulting in the transport of *Abies* pollen from the southern Cascade Range) and the east (the direction of *Artemisia*-dominated Great

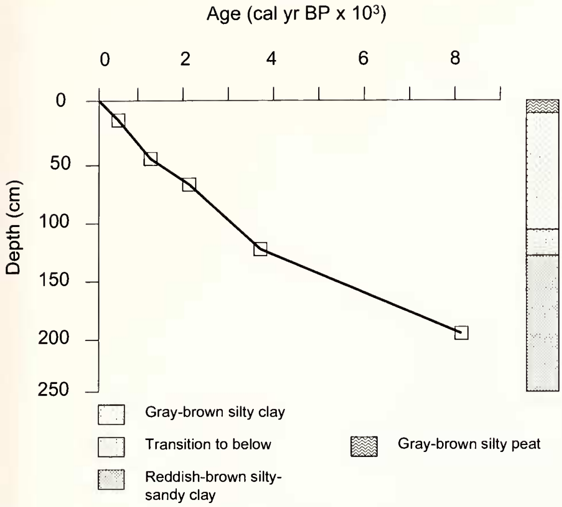

FIG. 2. Age-Depth curve for the five radiocarbon dates obtained from the Flycatcher Basin sediments, along with a sediment description of the profile. Ages are given in Table 1. The age model is based upon a linear interpretation of the median probability age for the sample.

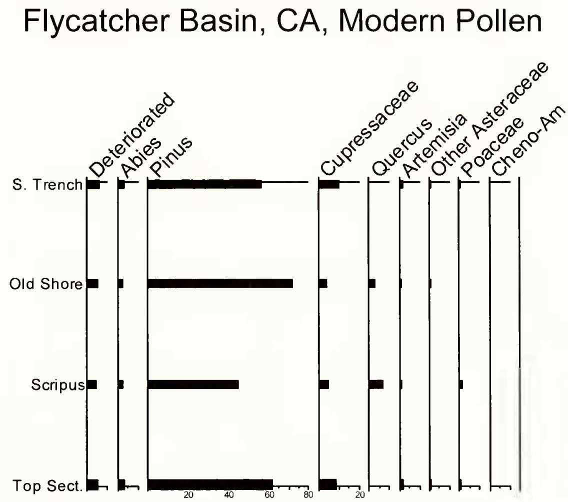

FIG. 3. Dominant pollen types in the modern pollen samples from Flycatcher Basin. Samples were obtained from four locations in the modern basin.

Basin steppe vegetation). The occurrence of dwarf mistletoe (*Arceuthobium*) in two samples is consistent with the presence of a dense *Pinus ponderosa* forest on the south side of the basin, since pollen of this conifer parasite is not widely dispersed (Anderson and Davis 1988). Though the basin was dry at the time of fieldwork, pollen of disturbed ground plants (e.g., Cheno-Ams – only a single grain recovered from the four samples) was very rare. Pollen of damp-ground or aquatic plants (Brassicaceae, *Polygonum amphibium*, *Thalictrum*, *Alnus*, *Potamogeton*, and Cyperaceae) was consistently found, indicating recent basin wetting. Spores of quillwort (*Isoetes*) and aquatic algae were recovered from the south trench and *Scirpus* sites, but not from the old shoreline. This is probably a reflection of the greater time that water covered the central portion of the basin, suggesting that the old shoreline is an ephemeral feature, or that considerable time has passed since the highest water level was attained.

Fossil Pollen and Macrofossil Assemblages

Forty-two fossil pollen samples were analyzed from Flycatcher Basin, representing an average of 195 yr between samples for the entire record, but 105 yr between samples for the late Holocene (last 4500 yr) only. We identified 31 pollen and spore types. Pollen preservation varied throughout the core. Preservation was very good in the modern surface samples and in the upper 40 cm of the core, where deteriorated grains averaged less than 10%. Below this to ca. 140 cm, deteriorated pollen comprised approximately 20 to 30% of the sum; pollen was essentially absent in sediments below 140 cm. We believe that the decline in pollen preservation with depth is probably related to greater incidence of drying of the sediment in older portions of the core, as evidenced by the oxidized appearance of the sediment, and as discussed below. As expected, pollen concentrations were greatest in the modern samples and near the core top, and declined with depth (Fig. 4).

Vegetation and climatic changes are interpreted from the terrestrial pollen percentage (Fig. 4) and wetland and aquatic remains (Fig. 5) diagrams. Pollen and macrofossils were essentially absent in the bottom 50–60 cm of the core. Pollen was well-preserved in sediments deposited subsequent to approximately 4500 cal yr BP. However, pollen concentrations and macrofossil abundances increased dramatically in sediments deposited over the last ca. 2000 yr (Figs. 4 and 5). Dominant pollen types were those common in the modern surface samples, including *Pinus*, Cupressaceae, *Quercus*, *Abies* and Asteraceae. Small amounts of *Artemisia* were found in virtually all samples. The macrofossil samples contained ca. 25 plant and animal taxa. Most taxa were aquatic or semi-aquatic; of terrestrial species, only the remains of *Pinus ponderosa*, *Arctostaphylos* cf. *patula*, and seeds of a Rosaceae were recovered.

Pollen Zone FB-I (ca. 8300 to ca. 4500 cal yr BP). Pollen and macrofossils were essentially absent from this zone (Fig. 4), and charcoal concentrations were also low. Sediments were reddish-brown, indicating persistent exposure and greater oxidation compared to overlying sediments. Oxidation promotes intense decom-

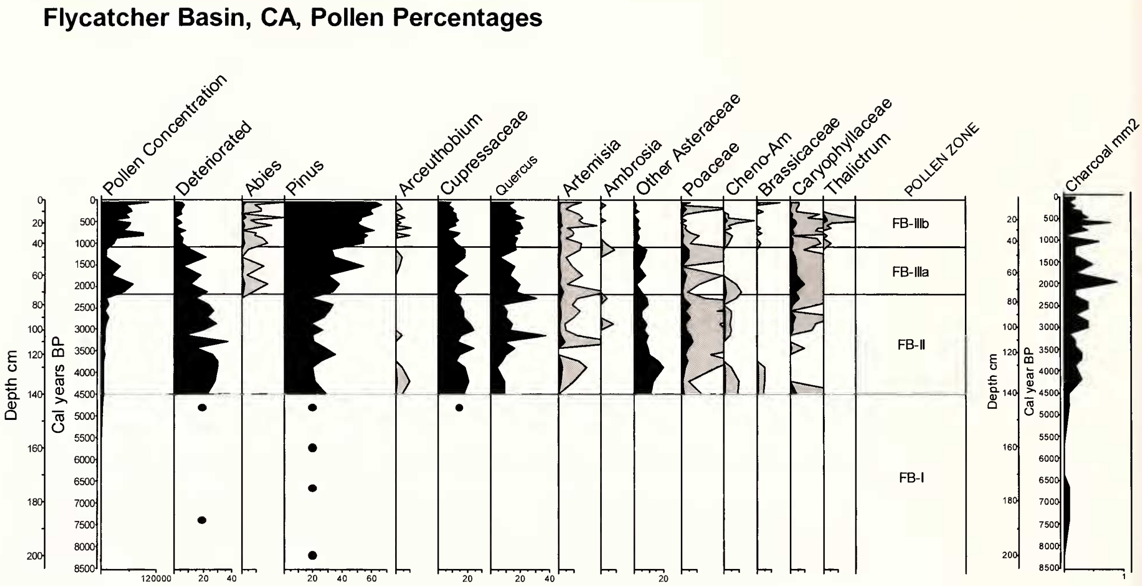

FIG. 4. Pollen concentration, proportion of degraded pollen, and terrestrial pollen percentages for common terrestrial pollen types in the Flycatcher Basin sediments. Little pollen was recovered below 140 cm depth (presence only denoted by a dot). Silhouette = pollen percentage × 10.

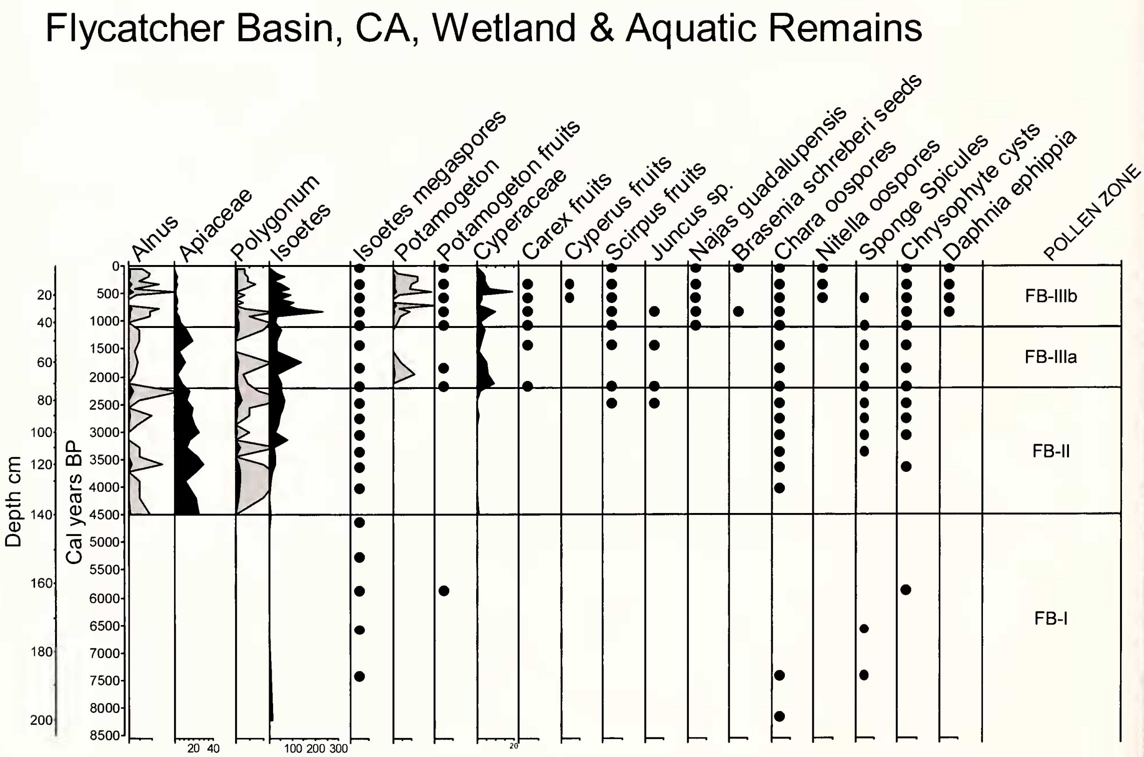

FIG. 5. Occurrence of aquatic pollen (continuous curves) and plant and animal macrofossils (dots) from the Flycatcher Basin record. Silhouette = pollen percentage × 10.

position, which probably accounts for the lack of preserved organics.

Pollen Zone FB-II (ca. 4500 to ca. 2200 cal yr BP). Pollen percentages in this zone were dominated by *Pinus*, Cupressaceae (likely *Juniperus*), and Asteraceae, with smaller amounts of Poaceae, *Artemisia* and *Quercus*. Poaceae, Cupressaceae and Asteraceae pollen declined toward the end of the zone. Degraded pollen was less than in Zone FB-I, averaging 20%. Pollen concentrations were lower than in overlying sediments (see below). The ratio of arboreal to non-arboreal pollen was generally low, indicating dominance by taxa such as Asteraceae, Poaceae, and Apiaceae. Charcoal was present, but the quantity was lower than in the subsequent zone. Macrofossils were entirely of aquatic taxa, dominated by *Isoetes* and *Chara*, with occurrence of freshwater sponge spicules and Chrysophyte cysts (Fig. 5).

Pollen Zone FB-III (ca. 2200 cal yr BP to present). Two subzones (FB-IIIa, ca. 2200 to 1100 cal yr BP; FB-IIIb, ca. 1100 cal yr BP to present) were identified. Pollen concentration for the entire zone increased fivefold over Zone FB-II. The percentage of degraded pollen declined toward the surface. Conifer pollen, particularly *Pinus*, increased during this zone and that of *Arceuthobium* was more common than below. *Abies* pollen was first recovered in FB-IIIb, while values of Poaceae and Asteraceae were lower in this subzone. Charcoal concentrations generally increase during FB-III over the previous zone.

The richness of aquatic taxa increased substantially in Zone FB-III. Types common in FB-II continued here. Pollen and macrofossils of *Potamogeton*, sedges (both *Carex* and *Cyperus*), and tule (*Scirpus*) became abundant early in subzone FB-IIIa. Other rooted, floating aquatics such as *Najas* cf. *guadalupensis* (Sprengel) Magnus, *Brasenia schreberi* J. Gmelin, along with *Nitella*, became common in FB-IIIb. Ephippia of *Daphnia* were abundant, indicating more persistent standing water.

Discussion

The paleoecological record from Flycatcher Basin is important in understanding Holocene climatic events and their impact on the vegetation of the Modoc Plateau and vicinity, the stability of a major vegetation ecotone, and potentially the history of drought conditions there. Preservation anomalies are undoubtedly important in determining the characteristics of the fossil assemblages, particularly during Zone I time (ca. 8200 to 4500 cal yr BP). The generally coarser clastic sediment deposited during this period may indicate greater slopewash at that time, and the reddish-brown color is consistent with strong oxidation under subaerial conditions. This probably accounts for the lack of organic preservation. We interpret the mid-Holocene local environment of the basin as being a small, mostly dry depression.

After ca. 4500 cal yr BP fossil preservation and concentration increases, and these fossils suggest a mixed conifer – *Quercus* forest grew around Flycatcher Basin. This forest may have been similar to the modern forest, but more open (greater Asteraceae, Poaceae) and with less *Pinus* than today. Abundant sedimentary charcoal (Fig. 4) suggests regular forest fire, though our technique cannot estimate any potential changes in fire episode frequencies over earlier times. Distinctly modern forests developed by ca. 2200 cal yr BP when *Pinus* became the dominant conifer, growing with *Quercus*, in a more closed forest, perhaps with more frequent fire (Fig. 4). The record does not show any marked long-term changes in the importance of sagebrush (*Artemisia*) pollen over the last 4500 yr, and therefore suggests little if any change in the position of the ecotone between Californian (Cascadian) and Great Basin floristic provinces.

Wetland and aquatic species, including perhaps *Alnus*, became established within and near the site at this time also. *Alnus* does not presently exist in the basin, although it does grow along the Pit River. Because the modern surface samples (Fig. 3) yield amounts of *Alnus* pollen comparable to those found in samples from the stratigraphic column (Fig. 4) it is possible that these grains are not locally derived. The occurrence of *Isoetes*, *Chara*, Chrysophyte cysts and others indicate that water must have covered portions of the basin for much of the year, but a lack of floating aquatics suggests shallow water depths.

Pollen evidence from other sites within the region also suggests warmer and/or drier climates during the middle Holocene than today, which could have led to a regional lowering of water tables. During the middle Holocene, *Pinus*, *Quercus*, and Cupressaceae dominated forests of the Klamath (West 1989; Mohr et al. 2000; Daniels et al. 2005) and mid-elevations of the Sierra Nevada (Smith and Anderson 1992; Anderson and Smith 1994; Edlund 1996) regions. Chironomid-inferred temperatures suggest that the mid-Holocene was the warmest period in the Sierra Nevada (Potito et al. 2006). Although individual characteristics prevailed at each site, after ca. 4500–5500 cal yr BP the more mesic species *Abies* increased at all sites. Further north in southern Oregon, the middle Holocene at Diamond Pond was dry prior to 6200 cal yr BP, but after this groundwater tables rose, forming a permanent lake (Wigand 1987). These data are consistent with a regional increase in effective annual precipitation, leading to higher groundwater tables, and establishment of persistent wetlands.

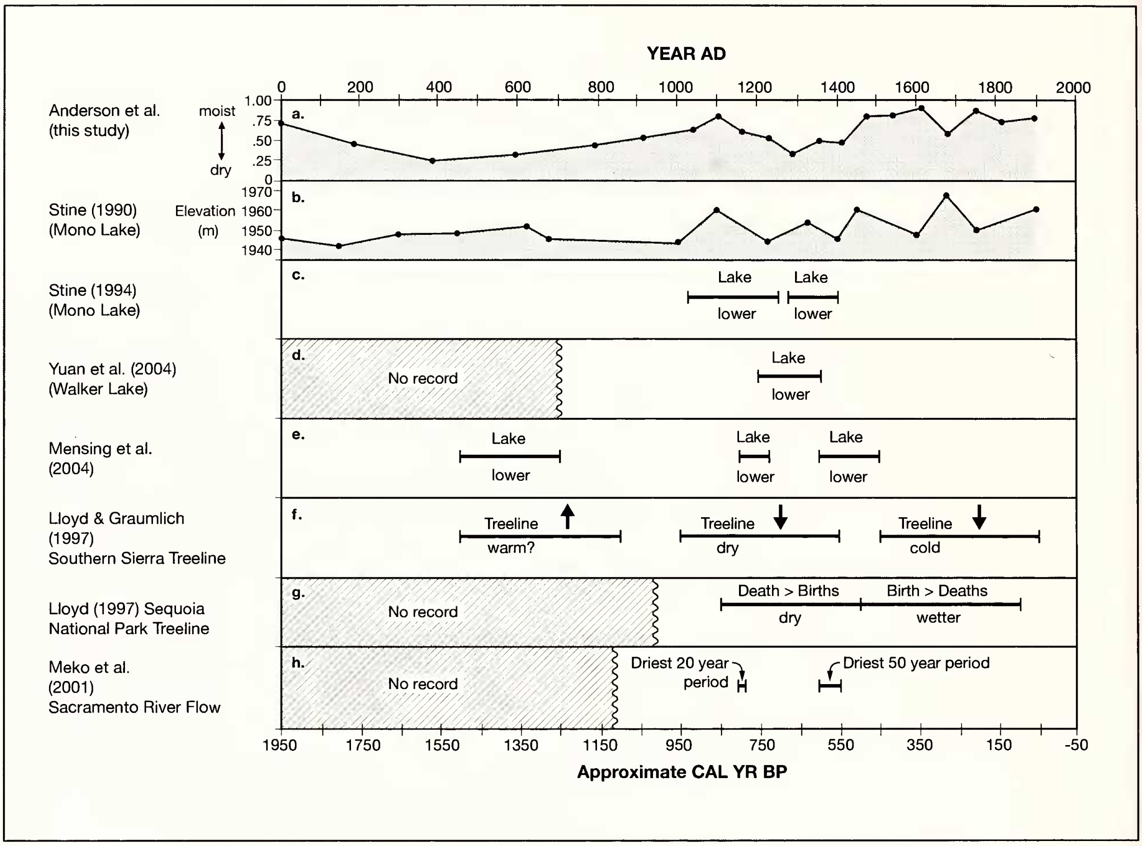

FIG. 6. Comparison of climate proxies for the last 2000 yr: a. Calculation of relative wet and dry periods using pollen function (*Polygonum amphibium* + *Alnus* + *Potamogeton* + Cyperaceae)/(*Polygonum amphibium* + *Alnus* + *Potamogeton* + Cyperaceae + Asteraceae + Cheno-am) (this study); b. Calculated elevation (m) of Mono Lake, California, levels (Stine 1990); c. Calibrated radiocarbon ages of submerged tree stumps at Mono Lake (Stine 1994); d. Period of lowest lake levels at Walker Lake, Nevada (Yuan et al. 2004); e. Calibrated ages of lowered lake levels at Pyramid Lake, Nevada (Mensing et al. 2004); f. Treeline fluctuations in the southern Sierra Nevada, California (Lloyd and Graumlich 1997); g. Relationship between tree death and germination at treeline in Sequoia National Park, California (Lloyd 1997); and h. Flow of the Sacramento River, California, from tree ring evidence (Meko et al. 2001).

The Latest Holocene

The development of modern conditions occurred during the last 2200 yr. *Pinus* increased within the area, while *Quercus* remained important and *Juniperus* declined. Indicators of open-ground such as taxa of Poaceae and Asteraceae also declined. The first occurrence of *Abies* pollen probably represents expansion of *A. concolor* in the Cascades to the west (Mohr et al. 2000; Daniels et al. 2005). Research here and from the Sierra Nevada to the south (Davis et al. 1985; Anderson 1990; Anderson and Smith 1994; Edlund 1996) established a continuous, incremental expansion of *Abies* during the late Holocene, suggesting a long-term increase in effective precipitation and soil moisture. During this period, the aquatic flora at Flycatcher Basin became particularly rich, indicating that the basin held permanent water, and that water depths were sufficient in most years to support floating aquatic plants, especially after ca. 1100 yr ago (Fig. 5).

However, using our equation to compare wet and dry pollen indicators over the last 2000 yr (see methods), our analysis suggests wet conditions periodically alternated with more arid climates during the latest Holocene (Fig. 6a). Although the pollen sampling interval varies over this time period, the ratio suggests generally dry conditions from ca. 1125 to 1450 AD, with another possible protracted dry period from ca. 100 to ca. 900 AD. Generally wetter periods occur from ca. 1000 to 1125 AD, and after ca. 1450 AD.

This reconstruction is very similar to the lake-level reconstruction for Mono Lake over the last 2000 yr (Fig. 6b; also Stine 1990). Lake levels at

Mono Lake are controlled by runoff from the Sierra Nevada, and were generally low prior to 1000 AD, peaked by 1100 AD, and declined between ca. 1150 and 1450 AD. After ca. 1450 AD, lake levels fluctuated, but generally trended upward. This latter period may have been driven by cooler temperatures and greater precipitation during the Little Ice Age, dated in the Sierra Nevada as after ca. 650 cal BP (Matthes glaciation; see references in Clark and Gillespie 1997).

We also compared the Flycatcher Basin record with several higher resolution records of climate variation for northeastern California and the Sierra Nevada, and for western Nevada (Fig. 6c–h.). The comparisons are particularly striking for the last ca. 1000 yr, with fewer data available prior to that. For instance, in a study of runoff of the Sacramento River in California, Meko et al. (2001) determined the driest 50-year and 20-year periods to be from 1140 to 1160 AD, and 1350 to 1400 AD, respectively. Similarly, numerous dates on submerged stumps from Mono Lake (1025 to 1250 and 1275 to 1400 AD; Stine 1994) suggest lowest lake levels then. Yuan et al. (2004) determined from δO^{18} analysis that the driest late Holocene period at Walker Lake, Nevada, was from 1200 to 1360 AD. At Pyramid Lake, Nevada, Mensing et al. (2004) determined major dry periods at ca. 1150 to 1225 and 1350 to 1500 AD. Each of these reconstructions suggests particularly dry conditions contemporaneously with the 12th to 15th century dry period at Flycatcher Basin.

Tree-ring and stand-age data from high elevation foxtail pine (*Pinus balfouriana* (Grev. & Balf.)) stands in the Sierra Nevada also confirm the Flycatcher Basin interpretations. Decline in upper elevation treeline due to drought occurred from ca. 1000 to 1400 AD (Lloyd and Graumlich 1997), with maximum drought between ca. 1250 to 1400 AD (Graumlich 1993), while tree deaths exceeded births from 1100 to 1450 AD (Lloyd 1997). However, contemporaneously with our reconstruction of wetter conditions at Flycatcher Basin after ca. 1450 AD, treeline data suggest cooler and wetter conditions in the Sierra Nevada (Fig. 6f. and g.).

Conclusions

Occurring at the transition between the Great Basin and the Californian-Cascadian Floristic Provinces, the paleoecological record from Flycatcher Basin exhibits affinities to both. Antevs (1948) defined a paleoclimatic sequence for the Great Basin as consisting of three distinct stages: the Anathermal (ca. 11,000–7000 yr ago; early Holocene), the Altithermal (ca. 7000–4500 yr ago; middle Holocene), and the Medithermal (ca. 4500 yr ago to present; late Holocene). Based upon the presence or absence of lakes in the Great Basin, this sequence defined a regime of effective precipitation changing from subhumid to arid conditions, followed by semiarid climates. Subsequent research has confirmed this sequence. The middle Holocene was warmer and drier than the early Holocene (Wigand and Rhode 2002; Tausch et al. 2004); Lake Tahoe was below its rim during this period (Lindstrom 1990; Benson et al. 2002), Pyramid Lake may have been at its lowest level (Born 1972), and Walker Lake was essentially dessicated (Bradbury et al. 1989). These conditions may have lasted until about 3500 yr BP in parts of the Great Basin (Tausch et al. 2004). But subsequent cooler temperatures, and increases in winter precipitation during the Neoglacial led to generally higher groundwater tables and greater persistence of lakes and wetlands in the western Great Basin (Wigand and Rhode 2002; Tausch et al. 2004).

By way of contrast, studies of high elevation vegetation change to the south in the Sierra Nevada defined an early Holocene xerothermic (Davis et al. 1985; Davis and Moratto 1988; Anderson 1990; Brunelle and Anderson 2003) ending by about 7800–6800 cal yr BP, after which effective precipitation increased, as shown by expansion of *Abies* and other upper montane species. Intensification of cooling and increased effective precipitation occurred after ca. 4500 cal yr BP (Davis et al. 1985), while additional evidence for cooling at ca. 2600 and 900 cal yr BP is evident at several locations (Anderson 1990). But, vegetation sequences from middle elevation sites in the northern Sierra show no evidence for expansion of *Abies* until after ca. 3900 to 4500 cal BP (Edlund 1996). However, the origination of a semi-permanent wetland, as determined by aquatic macroscopic remains, in Flycatcher Basin after ca. 4500 cal yr BP initially is consistent with its position intermediate between the Great Basin and Sierran sequences.

The record from Flycatcher Basin # 2, though covering only a portion of the Holocene, is important in our understanding of the late Holocene paleoenvironmental changes that have occurred in northeastern California. The ca. 4500-year pollen and plant macrofossil record is interpreted as a generally increasingly mesic sequence, with a long-term increase in groundwater recharge, yet interspersed by extended drought during the last 2000 yr. The paleoenvironmental changes in the Flycatcher Basin wetland are a local expression of a much broader climatic pattern, as shown by several studies of higher resolution proxies. The Flycatcher Basin demonstrates the long-term, centennial-to-millennial fluctuations in water availability in a region of rapidly expanding human population, with an increasing need for water resources.

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